V-22 Simulator Evaluation for Shipboard Operations

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Abstract

In June 1990, a preliminary evaluation of the Naval Air Warfare Center Aircraft Division (NAWCAD) Patuxent River's Manned Flight Simulator (MFS) motion base was performed to assess its value for pilot training and task familiarization for Dynamic Interface (DI) testing. Since that time, MFS engineers have made significant improvements in the areas of ship airwake and turbulence modelling, ship visual elements, and motion cueing. In early 1993, the DI department was tasked to perform an evaluation with a duel purpose. The first was to evaluate and document the fidelity of the V-22 flight simulator for the shipboard operations flight tests. The second was to identify the critical elements required to adequately perform various shipboard compatibility analyses and prepare project pilots for shipboard DI testing. The test consisted of 220 shipboard landings, 8 short take off's, and comprised a total of 16 flight hours.

Background

In 1985, the Manned Flight Simulator of the Naval Air Test Center, Patuxent River, Maryland was tasked by the V-22 program office to develop an aerodynamic model to support the V-22 flight test program. Additional mathematical models were developed, and a realistic cockpit procured. One of the many proposed applications for the simulator was to prepare V-22 pilots for shipboard compatibility flights called Dynamic Interface (DI) testing. One of the many objectives of DI flight testing is to identify wind-over-deck conditions (called launch/recovery envelopes) required for consistent safe helicopter operations from a particular class ship. The highest priority ship class to flight test the prototype V-22 was USS WASP (LHD-1). The initial shipboard trials were performed in December of 1990. Simulation engineers produced a visual model of the ship to prepare for the proposed flight test. One question was left unanswered..."What is the minimum fidelity of a simulator required to properly prepare pilots for shipboard flight operations?"

Purpose

The main purpose of this paper is to provide some insight into evaluating an aircraft simulation in a shipboard environment. In addition, procedures and analysis techniques will be outlined with special emphasis on experimental design.

TO WHOM IT MAY CONCERN:

Here is a copy of Professional Papers written by various people here at the Naval Air Warfare Center Aircraft Division. It was requested that a copy of each of the professional papers be sent to DTIC for retention.

If you have any questions, please contact Dorothy Reppel, 326-1709 or (301) 826-1709.

P.S. All the enclosed papers have been cleared for public release.

Introduction

"Experimental Design" seems to be the latest buzzword among human factors and test engineers. Budgetary constraints and high operating costs drive the engineer to know precisely how post-test experimental data will be handled to ensure maximum benefit. A machine is fairly simple to evaluate (if it is operating properly) because of its consistent and predictable nature. In flight testing, the test engineer's input variables include not only the aircraft and atmospheric conditions, but also the pilot controlling the machine. Certain information must be considered when collecting qualitative information from project pilots pertaining to total number of flight hours, flight hours in the specific model, hours in simulators, and number of shipboard landings. This information will help the test engineer choose which pilot will be most suited for a particular task or phase of the test.

What critical elements make shipboard operational simulation unique? The main elements are lack of adequate spatial cueing on final approach and hover, ship motion, sea state, and ship superstructure turbulence. The four main elements or subsystems which were evaluated at the MFS were the visual system, motion system, aural system, and ship airwake/turbulence models. The purpose of the evaluation was not to validate the aircraft aerodynamic model, but rather to identify the level of fidelity required to adequately prepare project pilots for shipboard operational flight testing. Each system was broken down into sub-systems or sub-elements to be evaluated, illustrated in table I.

There are many questions that arise while preparing for an evaluation of this nature. What is the minimum number of pilots required to provide information that is "statistically relevant"? How can one "standardize" a port approach? How does one account for the "learning curve" over the span of a two hour flight?...The list goes on. The scope of effort was the first thing to be addressed, with a test plan written to outline aircraft configuration, atmospheric conditions, procedures, data collection, etc. That information led to the number of test pilots and amount of simulator time required for the evaluation.

Description of the V-22 Flight Simulator

The MFS Six Degree of Freedom motion base system is designed to produce realistic motion throughout the flight envelope, particularly during the critical takeoff, approach, and recovery phases. The motion platform is controlled to provide roll, pitch, yaw, vertical, lateral, and longitudinal translation in any combination with $\pm$ 1 g acceleration. The motion system is equipped with a Wide-Angle Infinity Display Equipment II (WIDE II) visual display system. The WIDE II displays the computed scene from a COMPU-SCENE IVA visual system and consists of five projectors, a back projection screen, and a collimation mirror. The WIDE II provides a field of view of 160 deg in the horizontal plane and +15/-25 deg in the vertical plane.

Table I

SIMULATOR SUBSYSTEM EVALUATION MATRIX

SUBSYSTEM/MODEL	TASK	ELEMENT	COMMENT
Aural		Proprotor Gear Warning Altitude Warning	- Gear warning and altitude warning tones were evaluated on the flight deck.
Visual	180 degree position, turn to 90 and final approach to precision hover, touch down, lift-off to precision hover, lateral translation over deck edge, transition to forward flight	Crash Crane Tow Tractors Parked A/C Stern Wake LSE Ship Motion	- For each approach sequence, one element in column 3 was added to the baseline LHD-1 model to determine its impact on pilot workload. - The articulated LSE was evaluated based on landing position accuracy of the aircraft nosegear with respect to the crows foot. - Ship motion was evaluated on its ability to improve the realism of the shipboard environment, and to increase the difficulty of the landing task.
Ship Flowfield (Airwake)		Steady State Airwake (050 deg/15 kt) Turbulence Moderate/Severe Airwake + Turbulence Moderate/Severe	- Both the steady state airwake and turbulence models were evaluated separately. - In addition, the turbulence was superimposed on the steady state airwake and evaluated for realism with respect to aircraft response and flight control workload.
Motion	Same port approach sequence as above with the addition of Short Take Off (STO)	6 Degree of Freedom Motion Cues	- The evaluation of motion cueing was conducted through pilot comments. - The motion base was instrumented to supplement the pilots' qualitative evaluation.

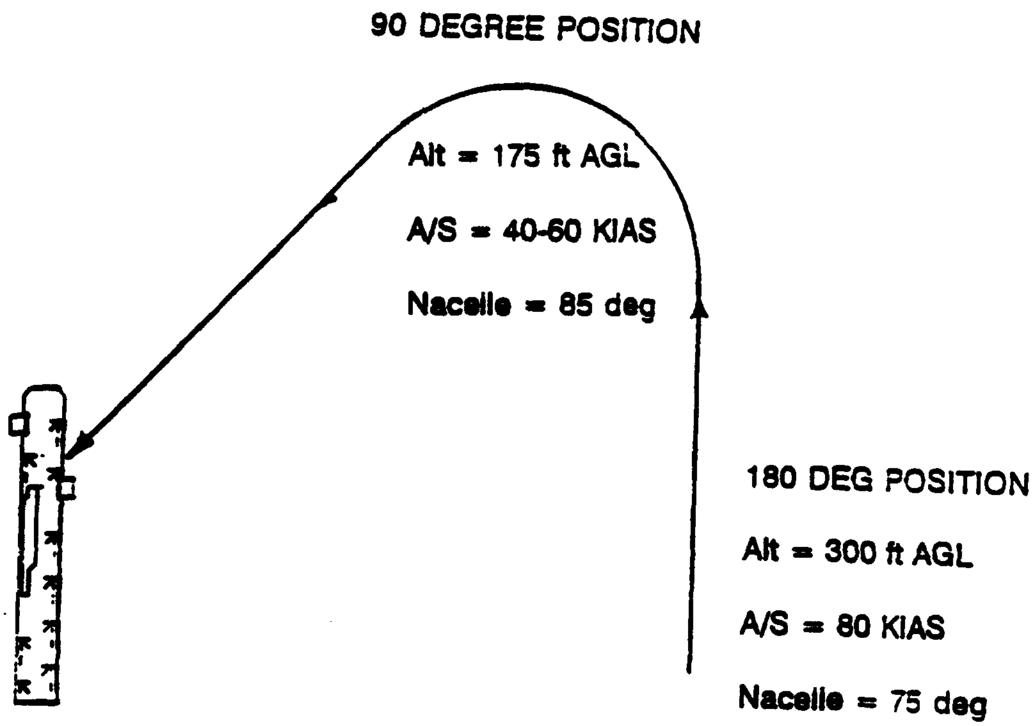
A rotor disk mathematical model is used to model the V-22 proprotors. A MicroVax II is used for the avionics system modeling. The ship airwake turbulence model is based on the NASA Dryden atmospheric turbulence model and CFD produced average flow velocities. The aural cueing model is generated through an Amiga sound processor, and is based on sounds recorded from the XV-15 and from prototype V-22 ground testing. The simulator also incorporates various atmospheric visual models, avionics and control system models, and landing gear/structural models.

Procedures

The simulator evaluation was divided into 4 general areas; the visual system, aural system, motion system, and ship airwake/turbulence model. Each system required a slightly different procedure for evaluation. The general procedure was to initialize the aircraft in the 180 deg position of a port delta pattern flying 80 knots at 300 feet with a 75 deg nacelle angle. The pilot would immediately roll the aircraft into a left descending turn until 45 deg relative to the ship centerline, adjusting Thrust Control Lever (TCL) and nacelle angle to control airspeed and rate of descent. The approach would terminate in a precision hover above the crows foot, and the aircraft would recover on spot number 7 aboard USS WASP ship model. The pilot would then lift off to a 15 ft precision hover, translate laterally past the deck edge, and transition to forward flight capturing a steady rate of ascent. The simulation would then be halted and the aircraft reset to the 180 deg position. Specific airspeeds and altitudes of the approach profile are illustrated in figure 1. Seven pilots flew in the overall evaluation, and each performed a specific number of approaches to the ship, depending on the subsystem being evaluated. All but one of the pilots had considerable shipboard operational experience, and two flew the V-22 aircraft on a regular basis. The subsystems were evaluated in the following order: aural, visual, motion, and ship airwake/turbulence. Each subsystem was evaluated separately, with each individual element of the subsystem "on" or "off" singularly for each recovery/launch sequence. Different methods of evaluation were employed on each subsystem which are outlined below.

Aural System

The aural system was the only subsystem that was evaluated purely on pilots' qualitative comments. No audio measurements were acquired. The intent of this evaluation was to determine if the aural system (producing proprotor, gear warning, and altitude warning cues) enhanced the realism of the simulation. Approaches were flown with and without aural cueing, and the pilots all preferred the aural system on. Seat shakers are usually used in conjunction with the rotor noise to emulate fuselage vibration, however, the tested simulator did not incorporate one.



Simulated V-22 Port Delta Pattern

Figure 1

Visual System

A common problem which exists with simulator visual systems is the data storage requirements of the visual models. Very complex visual models (like ships) are called "supermodels" because of the vast number of polygons or "faces" required to generate them. There is an upper limit to the number of faces a visual system is capable of displaying simultaneously. An overload will produce a variety of anomalies from slight ratcheting or slowing down of the visual update rate to portions of models disappearing.

The purpose of the visual system evaluation was twofold. The first was to assess the visual system in general; clarity, contrast, realism, etc. The second was to identify those visual elements which improved pilot performance and spatial cueing, choose which elements were not necessary or did not add to the realism of the shipboard environment, and indicate the visual models requiring improvement. A total of 6 visual elements, described in table II, were evaluated. Specifically, these were the Landing Signalman Enlisted (LSE), aircraft towing tractors (yellow gear), a crash crane, parked aircraft, the ship stern wake, and ship motion. The crash crane and parked aircraft were modeled primarily to add to the operational realism of the ship. The LSE may be used as a height cue and improve landing precision. The stern wake was implemented to make the ship appear to be making headway through the sea (it is, in fact, stationary) and to improve the pilot's acquisition of the ship's base recovery course (BRC). The ship motion was modeled from actual data from an amphibious assault ship. There was no intention to verify the ship motion model, only to show that it enhanced the operational realism of the simulation.

The visual system evaluation followed the general procedure, initializing in the 180 deg position of a port delta pattern and shooting repeated approaches to the ship. The pilot at the controls would execute 10 practice approaches to a baseline configured ship, and then begin the evaluation. The baseline ship model did not contain any of the enhanced visual elements listed in Table II. When the simulator was re-initialized after the initial practice approaches, a visual element was introduced, and an approach was performed. Each element was switched on and off in succession with each approach. The project pilots were not informed of the new visual element. Ship motion which was evaluated in the visual system portion of the test to assess its ability to enhance operational realism with the aircraft turning rotors on the flight deck. The pilots were specifically briefed not to make an effort to look for the new visual element, but rather to focus on shooting a proper approach and evaluating the difficulty of the task. Table III lists the sequence of the visual elements for each set of 8 approaches.

Table II

COMPUSCENE IVA VISUAL ELEMENTS

VISUAL ELEMENT	DESCRIPTION	LOCATION
Crash Crane	- 33.5 ft high Amphibious Assault Crash Crane, A/S 32A-36	- Directly aft of the superstructure island
LSE	- 6 ft tall Landing Signalman Enlisted, wearing an olive green jacket with yellow vest	- Forward and to the right of the aircraft
Articulated LSE	- Same as above, with dynamic arms for directing V-22 to correct landing position on spot	- Forward and to the right of the aircraft
Yellow Gear	- 5 Aircraft Towing Tractors, A/S 32A-31	- Aft port edge of the superstructure island, starboard of the safe parking line
Stern Wake	- White water aft of the ship	- Directly aft of the ship
Parked Aircraft	- 3 CH-53E aircraft, parked, noses inboard, side by side in folded configuration	- Directly aft of crash crane
Ship Motion	- Algorithm driven by 8 ft waves at 45° relative to ship centerline	N/A

TABLE III

VISUAL EVALUATION SEQUENCE

APP#	SEQUENCE A	SEQUENCE B	SEQUENCE C	SEQUENCE D
1	Base Config	Crash Crane	LSE	Crash Crane
2	Yellow Gear	Stern Wake	Crash Crane	Base Config
3	Crash Crane	Base Config	Stern Wake	Parked A/C
4	Parked A/C	LSE	Moving LSE	Stern Wake
5	Ship Motion	Moving LSE	Yellow Gear	LSE
6	Stern Wake	Ship Motion	Base Config	Ship Motion
7	LSE	Parked A/C	Ship Motion	Moving LSE
8	Moving LSE	Yellow Gear	Parked A/C	Yellow Gear

Notes:

1. The base configuration of USS WASP did not include any of the above enhanced visual elements.
2. The pilot at the controls flew 10 practice approaches to the base configured ship before performing the 8 approaches of sequence A, and flew 10 approaches to the base configured ship after the final sequence.
3. Only the right seat pilot flew the approaches outlined in the table, and performed sequences A and B, or A through C or D, depending on time constraints.
4. The pilot at the controls was not informed of the visual element evaluated with the exception of ship motion which was evaluated for increasing the difficulty of the recovery task, and enhancing realism while the aircraft was turning rotors on the flight deck.
5. The "Parked A/C" were 3 CH-53's parked side by side at spot 8, nose inboard, in folded configuration.

Motion System

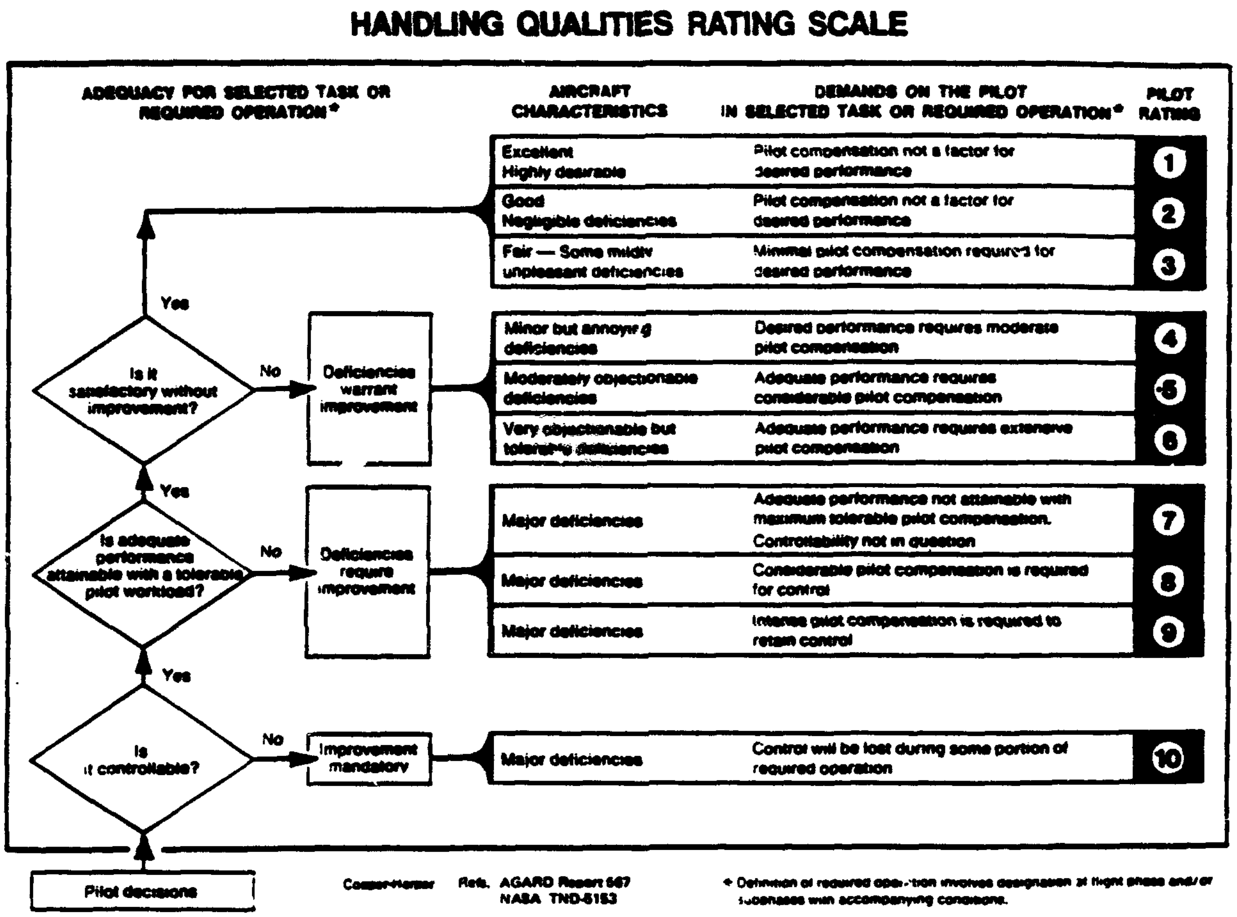
The motion system evaluation followed the general procedure, initializing in a port delta pattern and shooting repeated approaches to the ship. The motion base was instrumented to verify the pilots' qualitative evaluations, where Cooper-Harper handling qualities ratings (HQR's) were assigned to the hover task. Figure 2 illustrates the HQR scale. Two things are worth mentioning here. The copilot's job is to call out airspeeds and altitudes throughout the evolution, not to close his eyes and comment on the movement of the motion platform. The second thing is to avoid suggesting certain hypotheses during preflight briefings. These suggestions can sometimes lead to self-fulfilling prophesies.

Ship Airwake/Turbulence

The ship airwake/turbulence model evaluation followed the general procedure, initializing in the 180 deg position of a port delta pattern and shooting repeated approaches to the ship. The evaluation was divided into two phases. Phase one assessed the effect of the steady state airwake, and the second phase assessed the realism of the turbulence model superimposed on the airwake model. The relative (CFD produced) "ship airwake" wind-over-deck (050 deg relative to the ship centerline at 15 kt) was evaluated while handling qualities ratings were assigned to the task. The ship airwake model produced a steady state flow that varied with deck location, and did not contain a turbulent component. The turbulence model was vectorially added to the steady state airwake flow velocities and was evaluated with atmospheric turbulence ratings in addition to HQR's at mild, moderate, and severe turbulence levels. Since the ship was not making headway through the sea, the true wind and wind-over-deck was constant on approach. The turbulence level did not vary spatially. A schematic representation of the ship airwake/turbulence models is presented in figure 3. The evaluation was performed with motion disabled to reduce any coupling effects.

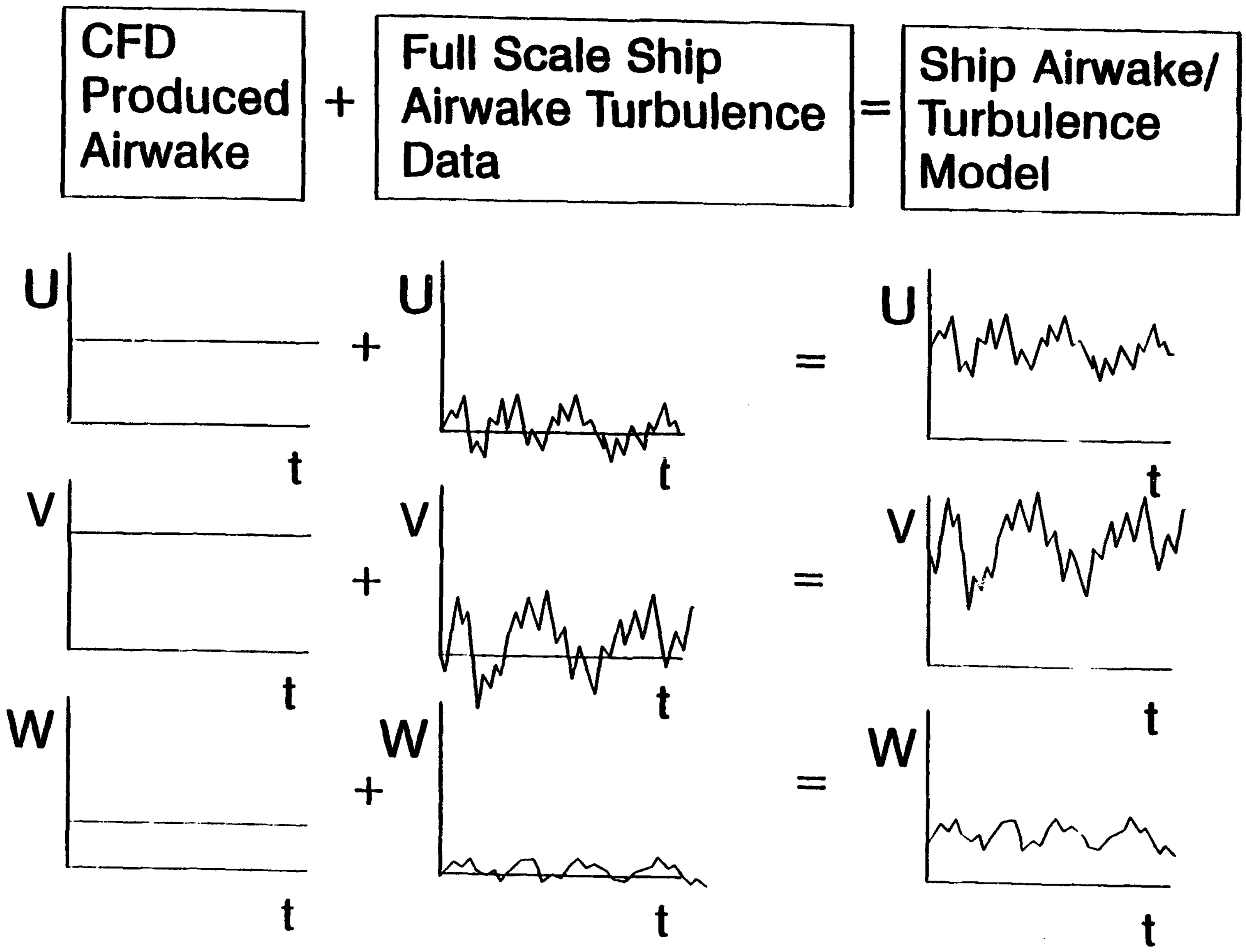
General Evaluation

The general evaluation followed the general procedure, initializing in the 180 deg position of a port delta pattern and shooting repeated approaches to the ship. Each pilot involved performed four approaches to the ship with all visual elements incorporated in addition to the motion system enabled, the ship airwake/turbulence model running, and ship motion running. The intent of this specific evaluation was to evaluate the MFS motion base with all systems enabled to assess the overall fidelity of the simulation during shipboard operational tasks. Minor annoyances in some subsystems do not manifest themselves with all systems operating. The exact visual elements employed during this phase of the evaluation and their corresponding locations are presented in table II. This was the only phase of the evaluation where all of the visual elements were displayed simultaneously.



Cooper Harper Handling Qualities Rating Scale

Figure 2



Ship Airwake/Turbulence Schematic

Figure 3

Analysis

When trying to solve a multivariable problem, a mathematician will vary one parameter while holding the others constant. This was the approach applied to the simulator evaluation. The only systems that were running throughout all phases of the evaluation were the aural system and the visual system. False or inaccurate motion cues would color the pilots evaluation of the turbulence model for example. Preflight briefings emphasized pilot focus on a particular facet of the simulation in an attempt to reduce the influence of other variables. It is impossible to completely separate the various systems influences on the pilot, so the procedures attempted to isolate the system to be evaluated. Additional items influenced the pilots, from field of view differences from the actual aircraft to task saturation.

Visual System

Each individual visual element may or may not contribute to the pilot's spatial cueing environment. The particular element may not be consciously noticed by the pilot, but still used for peripheral cues. The only way to establish the connection between the particular element (LSE for instance) and improved spatial cueing is to conduct many runs with and without the element randomly and evaluate certain parameters from a statistical standpoint. Each visual element analysis method will be addressed with the exception of the crash crane and parked aircraft, which were both beyond the pilot's field of regard in hover and did not improve their cueing environment. The overall visual system assessment was evaluated through a detailed post-flight questionnaire. Issues that were addressed were contrast, clarity, realism, field of view, and enhancing characteristics in addition to specific questions about the quality of the enhanced visual elements.

LSE

The purpose of the LSE is to direct the pilot to the desired deck spot using visual signals. His signals are advisory in nature, with the exception of waveoff and hold, which are mandatory. Does this six foot "object" on the flight deck improve the pilot's height cues? In order to find out, ten approaches were flown to the flight deck with the LSE static (no arm waving) and without the LSE. Standard deviation of the hover altitude was compared with and without the static LSE, and the data indicated little difference between the two. The pilots comments suggested that the visual model of the LSE appeared two-dimensional and provided little height cues.

Ten approaches were flown to the ship with and without the articulated LSE present. The pilots were briefed to hold a 15 ft precision hover over the spot using the articulated LSE for assistance in aircraft position. Landing accuracy should have been improved with the articulated LSE present. XY coordinate data was gathered indicating landing position of the nosewheel relative to

the nosewheel deck marking with and without the articulated LSE present. A dispersion analysis was performed on the two sets of data to determine the improvement in landing accuracy. Just looking at the plot of nosewheel positions made it obvious that the LSE reduced the dispersion. Engineers usually want a specific value which reflects the statistical significance of the presence of some input variable. That is accomplished through dispersion analyses. In the data scatter, the longitudinal position of the aircraft was consistently aft of the flight deck nosewheel mark, whereas the lateral positions were symmetric to the mark. Comparison of the field of view for the aircraft and the simulator cockpit showed a limited downward field of view in the simulator (no chin bubbles) which gave the pilots the impression that they were further forward than they actually were. This may or may not have caused the tendency to land aft of the spot. Some visual cues are as subtle as rusted rivets on the superstructure face for height cues, or a microtextured flight deck surface simulating oil/hydraulic fluid stains for better acquisition of drift cues.

Stern wake

One of the pilots' complaints was the limited sideward field of view making it more difficult to acquire the ship when turning through the 90 deg position in the port delta pattern, however, that portion of the evaluation was performed with the left projector inoperative. A wake of churning white water aft of the ship could possibly improve the pilots' acquisition of the ship BRC to line up on the 45 deg relative to the ship centerline. Fifteen approaches were executed to the ship with and without the stern wake present. The aircraft nosewheel X and Y positions were plotted to illustrate a two dimensional flight path (as seen from above). All of the runs, grouped by pilot, were superimposed to see if there were more deviations in flight path with the stern wake than without. The data suggested that the stern wake did not provide the necessary cues to improve BRC acquisition. Some pilots commented that the contrast should be greater between the stern wake and the surrounding sea surface. Once again, the pilots were briefed to shoot repeated approaches to the ship without regard to the single enhanced visual element added to the visual scene. The approaches flown with and without the stern wake present were not flown back to back, but randomly according to the visual element sequence listed in table III.

Ship Motion

The ship motion generated during the evaluation, based on 8 ft waves at 45 deg relative to the ship centerline, was ± 2 deg of roll and ± 1 deg of pitch. Unless reminded, the pilots did not notice the ship motion on short final. When the aircraft was on the flight deck, pilots commented on the rise and fall and roll of the bow relative to the horizon. One pilot suggested there was a slight increase in control workload while "chasing the deck" to make the final adjustments to land. Several pilots noticed that the ship motion was not in synch with the aircraft motion while

parked on the flight deck. Superimposing the aircraft attitudes over the motion platform attitudes revealed that the aircraft was out of synch in pitch with the ship motion.

Yellow Gear

The yellow gear definitely added to the operational realism of the shipboard environment, however pilots commented that the locations of the tow tractors did not lend themselves to improved cueing. Comparing the precision hover task with the yellow gear to the baseline ship resulted in little difference between the two. The longitudinal, lateral, and vertical standard deviations were similar.

Motion base

A common question posed to the simulation community is whether motion plays a significant part in the positive transfer of training. The test pilots participating in this evaluation had varied opinions. Simulator motion algorithms designed to create the perception of motion fall short because of the complex sensors in the human body. Accelerations are sensed through kinesthetic and vestibular cues. Kinesthetic receptors are located throughout the body from the organs to the skin. The vestibular system, located in the head, senses linear and angular accelerations. When an actual aircraft accelerates forward, the body's sensors transmit signals in harmony with the visual signals to the brain. A motion base must initially reproduce the forward acceleration followed by a pitch up to allow the pilot's body weight vector to give the impression of continued forward acceleration. Now we have a situation where the linear acceleration sensors are providing one bit of data while the rotational sensors are providing data which does not correspond to the visual information. Most pilots respond to this disparity of information by getting motion sickness.

Launch/recovery evolutions are rather benign with respect to linear and angular accelerations. The only areas of pronounced motion during the test were on the onset of the left turn out of the 180 deg position in the port delta pattern, and during a flare on short final to reduce an excessive closure rate. The pilots had various comments, which were confirmed or denied based on comparing the "aircraft" motion data to the motion base instrumentation data. Additionally, flight control position data were analyzed with and without motion to see if the motion sensation reduced flight control workload.

Overall System Evaluation

This was perhaps the most difficult phase of the evaluation. The execution was not an issue, but the analysis could become complicated. Data were recorded, but the bulk of the information gathered came from pilot comments and thier perceptions of the simulation fidelity. Here is where statistical significance really

rears its ugly head. If one out of three pilots comments that the simulation is below the fidelity required to adequately train pilots for shipboard operations, does that mean one can state that 33% of the pilots believe the simulation is inadequate? The statement is not misrepresenting the statistics, however, it could very well be misrepresenting the truth. Perhaps if 10 pilots were queried, all but the strong willed one would answer positive. Suddenly the "statistic" dropped to 10 percent. The reality of the situation is that the test engineer must decide in the beginning what will be considered statistically relevant and stick with it, letting the readers know what population sample the "statistics" are based upon. The law of diminishing returns applies here with the number of runs executed under a particular condition. Here the trade off is between the data collected and the money and time spent.

Conclusions

The general procedure for analyzing various subsystems required to simulate an aircraft operating in a shipboard environment was presented. Specific analyses were outlined in addition to subjective rating scales for qualitative pilot data. One of the most crucial parts of a simulator evaluation is limiting the coupling between systems to reduce the influences on the pilot controlling the machine.

Acknowledgements

The author would like to acknowledge the dedicated team of professionals at the Manned Flight Simulator who were instrumental in the development of the V-22 simulation, and who are continuing to improve it. In particular, the engineers whose efforts most significantly contributed to the application of the simulator for shipboard operational training are Mr. Danny Campbell, Pierre Conley, and Mr. Kurt Long for their extensive efforts on visual modelling, Mr. Don Gaublomme for his efforts in the development of the ship airwake/turbulence models, Mr. Jeff Weathers for his development of the flight control system laws, Mr. Chris Mullaney for his efforts improving the motion system, and Mr. Joe Kleponis for his professionalism and exceptional attitude while supporting the test effort and running the simulation.

MEMORANDUM 3/3/94

From: Bill Reddy (RW40W)
To: Route Chain

Subj: PAPER SUBMITTAL TO THE ROYAL AERONAUTICAL SOCIETY CONFERENCE ON ROTORCRAFT SIMULATION

Encl: (1) Paper entitled "V-22 Simulator Evaluation for Shipboard Operations"

1. In mid September 1993, an abstract was submitted to the Royal Aerona[illegible] Society, and was accepted in early January 1994. Enclosure (1) will be published internationally. It takes a substantially longer time to route a paper published through an international organization than for AHS or AIAA. I was unaware of this and did not prepare adequately for the extra time required. The due date for this paper to be sent to England is 31 March 94. The conference is being held in mid May.

2. Enclosure (1) is a procedural paper, and does not contain specific results from the evaluation. A representative from TID suggested persuing a paper clearance through the acting Executive Director of FTEG. This would allow the paper to be cleared locally.

Thank You

V/R

Bill Reddy

Bill Reddy